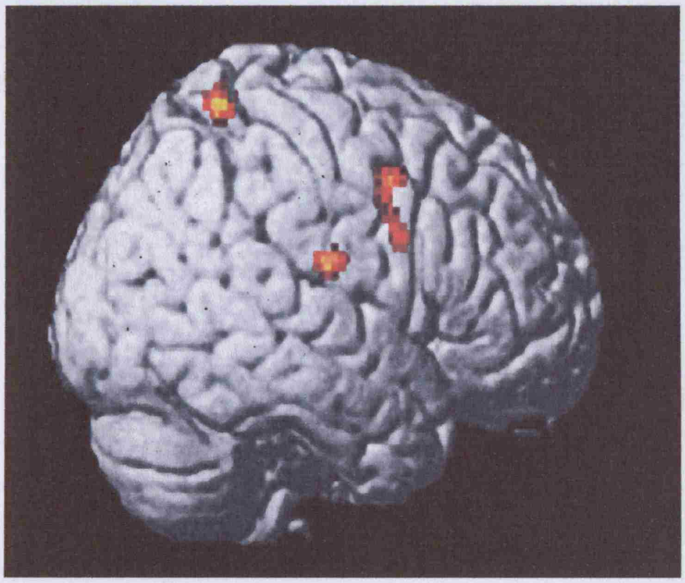
A Voxel Based Morphometry Investigation into Brain Abnormalities in Different Subsets of Developmental Dyslexia



Caroline Louise Ellis, BSc

Wellcome Department of Imaging Neuroscience

Institute of Neurology

Submitted as Partial Fulfilment of the Requirements for the MSc in Clinical Neuroscience, University of London 2006

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Acknowledgements

Firstly I would like to thank my supervisor Professor Cathy Price for all her help, support, patients and inspiration throughout this project.

I would also like to thank Odette Menign and Sasha Muldoon for their help with recruitment, data collection and analyses and Caroline Catmur for performing the WAIS testing.

A special thanks also to Professor Robert Turner for all his help and guidance throughout the year.

Contributions

Study design: Professor Cathy Price

WAIS testing: Caroline Catmur

Behavioural testing: Caroline Ellis, Odette Mengin and Sasha Muldoon

Statistical analysis of behavioural data: Caroline Ellis and Odette Mengin

Statistical analysis of MRI data: Caroline Ellis and Professor Cathy Price

Data Collection: Caroline Ellis, Odette Mengin and Sascha Muldoon

Wordcount :
8 975

Abbreviations

RT: Reaction time

MRI: Magnetic resonance imaging

fMRI: Functional magnetic resonance imaging

PET: Positron emission tomography

DTI: Diffusion tensor magnetic imaging

PRPS: Poor readers poor spellers

PSGR: Poor spellers good readers

SD: Standard deviation

WAIS: Wechsler adult inventory scale

WRAT: Wide range achievement test

Wtar: Wechsler test of adult reading

NART: New adult reading test

HOMSYN: Homophone and synonyms test

phAB: Phonological assessment battery

VBM: Voxel based morphometry

MDEFT: Modified driven fourier transform sequence

SPM: Statistical parametric mapping

CSF: Cerebral spinal fluid

Abstract

Several previous studies have reported that brain structure in developmental dyslexics differs from that of non-impaired readers. The results, however, have been inconsistent across studies and are not highly significant. The hypothesis driving the present study is that the inconsistent and weak effects are as a consequence of individual variability in how dyslexia manifests. On the basis of a previous unpublished study at the Wellcome Department of Imaging Neuroscience, it has been proposed that adolescents with reading impairments can be subdivided into those who have worse reading than spelling (henceforth referred to as dyslexics) and those that have worse spelling than reading (henceforth referred to as dysgraphics). The aim of the present study was to investigate whether this categorisation was also appropriate for adult university students with a history of reading impairments.

The project involved detailed behavioural testing and structural MRI acquisition on 29 adults, 16 of which had previously been diagnosed with reading difficulties. On the basis of their behavioural results, the literacy impaired group was divided into two groups: dyslexics and dysgraphics. As predicted by their diagnosis, both groups had worse spelling and slower reading than the non-impaired readers. In addition, both groups had less grey matter than controls in two left hemisphere regions that have previously been associated with the "phonological loop". Critically, however, the structural MRI data also confirmed a double dissociation

between grey matter reductions in the dyslexics and dysgraphics. The dyslexics had less grey matter in the right hemisphere phonological areas and the dysgraphics had less grey matter in the cerebellum. These findings support the hypothesis that abnormal brain structure depends on the type of reading impairment.

1: Introduction

1.1 Dyslexia

The disorder currently known as dyslexia was first described over a century ago by Pringle-Morgan and Hinshelwood in 1896. It was suggested that difficulties in reading and writing were infact due to 'Congenital word blindness' (As reviewed in Snowling, 2000). Since this point the theory of 'Word blindness' has largely been considered obsolete when the first consensus on developmental dyslexia met in 1968 by the World federation of Neurology:

> *'it is a disorder manifested by difficulty in learning to read, despite conventional instruction, adequate intelligence and sociocultural opportunity. It is dependent upon fundamental cognitive disabilities which are frequently of constitutional origin.' (reviewed in Snowling, 2001)*

This early definition has largely fallen out of use due to its weakness in that it offers diagnosis through exclusion. Currently developmental dyslexia is defined as '*a specific difficulty in the acquisition of reading and writing in spite of preserved general intelligence, learning opportunity, motivation or sensory acuity*' (World Health Organisation, 1993). The term dyslexia is often described as an 'umbrella term' in that it is very broad categorisation of all severities. This broad categorisation has lead to a variety of neurobiological studies into dyslexia, to ascertain differing groups and also the neural correlates associated with the varying degrees of the disorder. Although current studies report a wide range of behavioural deficits, any variance between subjects might reflect different types of dyslexia.

Dyslexics have been noted to have deficits in phonological processing skills (Bradley and Bryant, 1983; Stanovich, 1988) leading to poor literal rapid picture naming (Wolf,1986), auditory perception (specifically non speech sounds) (Tallal et al., 1993), visual perception and visuomotor control (Eden et al.,1996), motor skills and automatic balance (Nicolson and Fawcett, 1995) and finally information processing speed (Wolf, 1991).

1.2 Theories of Dyslexia

The wide range of behavioural manifestations as well as the complexity of reading and writing systems has meant that currently no unified theoretical perspective of dyslexia has been determined, yet many theories are currently proposed. The existing theories can be broadly grouped into two categories, those that occur at a processing/behavioural level (phonological and Sensori-Motor theories) and those that occur at a neuronal level that is on a biological basis (Cerebellar Deficit and Magnocellular theories).

1.2.1 Phonological hypothesis

The phonological hypothesis is a reduction in ability to identify and manipulate the sounds in speech. Phonological skills are essential when learning to read, it was hypothesised by Snowling and Hulme (1994) that children whom have a well specified phonological representation at the stage when they are learning to read are at an advantage to establish any links between the letters of printed words and the sound of spoken words. Reading itself is composed of alphabetic characters representing phonological constitutes under orthographic rules, but when these rules are absent or inconsistent the subsequent learning of grapheme-phoneme associations is notably arduous, inhibiting the reader greatly (Shaywitz et al., 1998). Hence it has been argued that dyslexic individuals may hold poorly specified phonological representations due to poor phonological encoding in comparison to a normal reader (Snowling, 2000). There is an abundance of evidence that phonological impairment is correct in pinpointing cognitive difficulties that are putative causes of reading failure (Snowling, 2000). A study by Ramus et al, (2003) indicated via the use of phonological, auditory, visual and cerebellar/motor tests that every dyslexic tested exhibited phonological deficits, with limited incidence of other deficits.

Non-literacy skills such as naming are also affected by phonological impairments (Wolf, 1991), which may be attributable to a lack of correct lexical and phonological word representation. Whether this deficit is a result of a single or common deficit is still unknown, studies by Wolf et al (2002) and Compton et al

(2001) have postulated that these deficits are relatively independent and additive but this is not conclusive.

In summary, a deficit in phonological skills is seen as a critical behavioural component in developmental dyslexia although in criticism this theory lacks the ability to explain the occurrence of other sensory and motor deficits (Ramus et al., 2003).

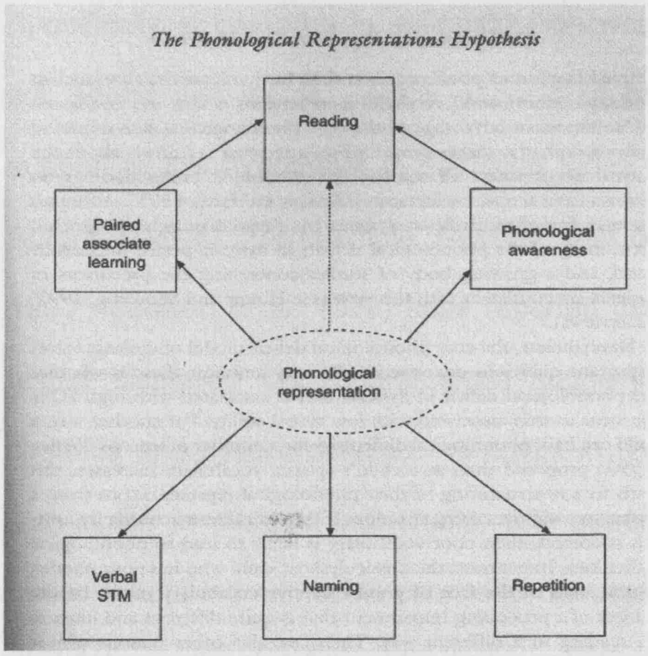


Figure one: a flow chart of the phonological hypothesis (adapted from Snowling, 2001).

1.2.2 Cerebellar deficit Hypothesis

This biological hypothesis claims that the dyslexic cerebellum is mildly dysfunctional and that a number of cognitive difficulties ensue, consistent with the recent view that the cerebellum plays a role in cognitive functions (Ramus et al., 2003). Of the many functions that has been linked to the cerebellum is the automatization of performing motor skills (Fawcett, Nicolson and Dean, 1996; Nicolson and Fawcett, 1994; Fawcett and Nicolson, 1999; Nicolson et al., 2001). Specifically, a reduction in automatization would affect an individual's ability to link sound and words. Many aspects of behavioural research have added support to this hypothesis in particular those testing motor skills (Balance and Automatization). For example, Nicolson and colleagues (Nicolson and Fawcett, 1990; Nicolson et al, 1999) have reported that up to 80% of dyslexic children tested displayed behavioural signs suggestive of cerebellar deficit, namely dystonia and dyscoordination. A deficit in time estimation (non-motor task) is also noted in dyslexic individuals, with support obtained via comparison with patients suffering with acute cerebellar damage (Nicolson et al, 1995). Deficits in eyeblink conditioning have also been noted in dyslexic subjects (Nicolson et al, 2002) and this classic conditioning mechanism involves the cerebellum.

Although the cerebellar theory can explain both motor and non-motor functions, it is not intuitive to infer a cerebellar deficit as the causal factor explaining higher cognitive deficits in dyslexia (Wimmer, Mayringer and Lanerl, 1998).

The alternative hypothesis suggests that the cerebellum exerts a more modulatory influence on other brain regions responsible for the underlying deficits observed in dyslexia (As reviewed in Zeffiro and Eden, 2001).

1.2.3 General Sensorimotor Hypothesis

The general sensorimotor theory indicates that a combination of both sensory and motor deficits, such as auditory, visual, balance and co-ordination may lead to developmental dyslexia.

Sensory and/or motor disorders have a higher preponderance in dyslexic individuals than when compared to the general population with a large proportion of dyslexic individuals having a co-occurrence of visual and auditory problems (Van Ingelheim et al, 2001). Nevertheless, Ramus (2003) indicates a major flaw in past studies that focused on one area of deficit (auditory, visual or motor) with limited assessment of the other modalities. That is that this fails to evaluate the multi-modal deficits that affect approximately one third of dyslexics. In contrast, Chiappe et al (2002) tested auditory, motor and visual processing within the same subject group. Although an overlap between the varying deficits does and can occur, some dyslexics still only fulfil the phonological hypothesis with an absence of any sensorimotor impairment. In light of this criticism 'the temporal processing impairment theory' which is an extension of the magnocellular hypothesis, offers the ability to account for perceptual and motor symptoms witnessed in dyslexics via a general dysfunction of the processing of brief stimuli in rapid succession, within different modality specific magnocellular pathways (Van Ingelheim et al, 2001; Hari and Renvau, 2001; Wolf, 2002).

1.2.4 Magnocellular Hypothesis

The magnocellular hypothesis offers a biological explanation for the sensorimotor hypothesis and refers to abnormalities within the cells of the brain, concerned primarily with visual input, although it also takes into consideration auditory and tactile processing abnormalities. Support for the magnocellular hypothesis has been based on observations of physiological abnormalities within medial and lateral geniculate nucleus of dyslexic brains (Livingstone et al, 1991; Galaburda et al, 1994).

The magnocelluar theory is often viewed as a unifying concept that tries to integrate all possible deficit modalities into one, including visual, auditory and tactile (Ramus, 2003) as well as the cerebellar deficit model, on the basis that all these systems receive input from the magnocellular systems (Stein et al, 2001). The magnocellular hypothesis broadly takes in the visual deficit hypothesis, and indicates a problem within the magnocellular pathway, which is implicated in certain visual skills such as directing visual attention, visual search and the control of eye movements, all skills required for reading (Stein and Walsh, 1997; Talcott et al, 2000).

Criticisms of the magnocelluar hypothesis mainly concentrate on the inability to replicate findings of auditory and visual deficits (Heath et al, 1999; Hill et al, 1999; Victor et al, 1993). The magnocellular system theory also suffers in its inability to explain the absence of sensory and motor disorders in a significant proportion of dyslexics (Ramus et al, 2003).

1.3 Neuroimaging Studies

Functional and structural imaging advances have proved beneficial in eliciting neuronal networks and associated activity within developmental dyslexia. MRI (magnetic resonance imaging) studies have their advantage over other imaging techniques, such as computerized tomography, in that the image produced by an MRI scan is not disrupted by the bone-brain interface and gray, white and CSF (cerebral spinal fluid) matter structures can be viewed separately depending upon the contrast used with appropriate conclusions drawn from the resultant data.

1.3.1 Functional Neuroimaging Studies

Functional imaging techniques including Positron Emission Tomography (PET) and functional Magnetic Resonance Imaging (fMRI) enable regions of brain activation to be measured and abnormalities detected. These functional imaging techniques in particular fMRI pertain to neurophysiological indices of brain functions (Friston, 2006) by observing changes in cortical blood oxygenation and hence metabolic activity during task activation with bold contrast (Turner and Ordridge, 2000) (Blood-oxygen-level-dependent response).

Functional imaging of developmental dyslexia has allowed the identification of abnormal responses during reading tasks (such as visual, orthographic, phonological and semantic decisions) in comparison to control individuals who have learnt to read normally. The regions with abnormal activation typically involve the inferior frontal gyrus, the left temporo-parietal region (composed of the supramarginal gyrus and the posterior superior temporal gyrus/wernickes area) (Rumsey, 1997; 1999; Horowitz et al, 1998) and bilaterally the occipito-temporal region (Brunswick et al, 1999; Shaywitz et al, 2002; McCrory et al, 2005) as well as the cerebellum (Brunswick et al, 1999; Nicolson et al, 1999). Critically, however, it is important to note that although dyslexia is associated with abnormal patterns of regional activation this does not indicate whether the abnormality caused the behaviour or the behaviour caused the abnormality.

1.4 Support for The Phonological Deficit Hypothesis

1.4.1 Temporo-parietal abnormalities

A reduced level of activation has been noted bilaterally in this region during reading (Rumsey et al, 1997; Horowitz et al, 1998). Reduced activation accompanied by visual deactivation were detected within the posterior temporal cortex bilaterally and the inferior parietal cortex (left) during pronunciation and decision making in normal individuals within a PET study (Rumsey et al, 1997), whereas dyslexic individuals demonstrated normal activation of the left inferior frontal cortex during both phonological and orthographic tasks, suggestive of an underlying bilateral neural deficit in the temporal regions.

Phonological assessment tasks have had an important role in indicating reduced bilateral activation of the temporal parietal and superior left middle temporal regions within dyslexic subjects (Paulesu et al, 1996; Shaywitz et al, 1998). Shaywitz et al (1998), concluded after assessment with phonological tasks that adult dyslexics had reduced activation in the posterior regions including Wernicke's area, the angular gyrus and the striate cortex, with increased frontal activation in older dyslexics who have learnt to use a compensatory strategy. The problem with these conclusions is that dyslexic participants are not able to perform phonological processing tasks as well as control subjects. Therefore differences that are noted in dyslexic individuals may be as a consequence, rather than a cause of their impaired behavioural performance as it was noted by Price and McCrory (2005). That is reduced left temporo-parietal activation may just reflect processing faults as a result of reduced access to the semantic system.

1.4.2 Left occipito temporal abnormalities

Even when task accuracy is matched, decreased activation is consistently noted in the left occipito-temporal cortex, including the left mid and anterior fusiform areas (Brunswick et al, 1999; McCrory et al, 2005; Shaywitz et al, 2002). This abnormality has been observed in English, French and Italian dyslexics when reading their own language (Paulesu et al 1996). Therefore it is not specific to any one orthography. Abnormal left occipito-temporal activation in dyslexics has also been reported during picture naming suggesting that it is not specific to orthography at all (McCrory et al., 2005). Instead, McCrory et al. (2005) suggest that abnormal occipito-temporal activation in dyslexics may reflect a general impairment in the integration of visual input with phonological information.

As with any of the current theories, however, phonological explanations of dyslexia do not explain why additional deficits are often observed in dyslexic individuals.

1.5 Support for the Cerebellar Deficit Hypothesis

1.5.1 Cerebellar abnormalities

The cerebellum is a key area in which many imaging studies have indicated changes in activation (Brunswick et al, 1999) and biochemical levels (Rae et al, 1998). Brown et al, 2001 also noted that dyslexics had decreased cerebellar grey matter density. An explanation for this decrease has not yet been confirmed. Nicolson et al (1999) conducted a PET study between dyslexic and control individuals. Both were asked to perform a range of tasks which would involve cerebellar activation in response to prelearnt or random finger movements. The results suggested that dyslexics had reduced activation irrespective of the task. However, as with other functional imaging studies, it is important to note that the results only offer an association between behavioural patterns and neural substrates. They do not explain how abnormal cerebellar activation during finger movements is related to the reading deficit.

1.6 Structural Neuroimaging Studies

Structural studies purely offer an ability to see structural abnormalities within the healthy human brain As opposed to the early post- mortem studies that highlighted structural differences in the brains of deceased dyslexics. Although there are obvious advantages to looking at the structure of in-vivo brains, structural imaging does not currently provide details on the physiological basis of structural abnormalities. In contrast, in post-mortem studies, Galburda was able to note that structural abnormalities were associated with ectopias and dysplasias of the neurons in dyslexic individuals, suggestive of atypical patterns of neuronal circuitry (as reviewed by Snowling, 2001).

The key brain regions associated with structural abnormalities in dyslexic include the cerebellum, anterior frontal gyrus and areas located around the Sylvian (left posterior Lateral) fissure. The supporting literature will be reviewed below.

1.6.1 Supporting studies

Leonard et al (2001) conducted a study of 3 adult groups of university educated subjects: controls, phonological dyslexics and reading disabled (non-phonological) categories. Four distinct findings were noted in the phonological dyslexia group. The first was marked rightward cerebral asymmetry. In contrast, there was a leftward asymmetry of the anterior lobe of the cerebellum and also in the planum and posterior ascending ramus of the sylvian fissure. Finally, all phonological dyslexics were found to have a duplication of Heschl's gyrus located on the left side (Leonard et al, 2001).

In a follow up study Eckert et al (2003), noted that reading, spelling and language measures were found to correlate with both the right cerebral anterior lobe and bilateral pars triangularis in the frontal lobe. Eckert et al. (2003) interpreted these findings as evidence that the frontal cerebellar system contributes to the symptoms of dyslexia (Eckert et al, 2003).

Using a different approach Brown et al (2001) used voxel based morphometry (VBM) and found dyslexic individuals had reduced gray matter particularly in the left temporal lobe and temporoparietoccipital cortex. Various other areas were also noted to be affected such as the left frontal lobe and bilateral superior cerebellar regions (Brown et al, 2001). However, these results are far from conclusive because of the very low statistical significance that the authors adopted. Brambati et al (2004) also report focal abnormalities in the inferior temporal cortex including the planum temporale and the cerebellar nuclei.

In addition, several studies have reported white matter abnormalities as well as grey matter abnormalities (Silani et al., 2005; Beaulieu et al, 2005; Klingberg et al, 2000). For example, Beaulieu et al (2005), used diffusion tensor magnetic resonance imaging (DTI), which highlights white matter in terms of structural integrity and noted a correlation between white matter density in the left temporo-parietal region and reading ability. Beaulieu at al (2005) also identified the posterior limb of the internal capsule as a faulty nerve bundle. White matter abnormalities provide some support for a disconnection account of dyslexia which proposes that the problem in dyslexics relates to disrupted communication between otherwise normally functioning areas (see also Silani et al, 2005).

Although findings are less than consistent within functional and structural studies, possibly as a result of a large variability of the dyslexic samples which in turn will reduce the significance of any results. Hence the question that must be asked is how do you divide dyslexics into different groups to account for variability? There are two possible options either by behaviour or brain structure/function, importantly though the two are related.

1.7 Motivation for Present study

The motivation for grouping dyslexics in this present study came from a previous structural imaging study of adolescent dyslexics Price et al (unpublished), whereby it was noted that correlations between brain structure and behaviour (reading and spelling) suggested that the critical variable was not the score obtained on individual tests, but the relationship between these scores. This hypothesis is based on data showing that cerebellar grey matter was lowest in those with worse spelling than reading. Thus, a correlation was found across controls and dyslexic groups that was not driven by either spelling or reading alone, but instead by the difference between the spelling and reading. Those with poorer spelling than reading had less cerebellar grey matter than those with poorer reading than spelling. On the basis of these results, it was noted that dyslexics could be divided into two different groups that corresponded to subgroupings previously proposed by Uta Frith in the 1980s.

1.7.1 Friths subgroups

Frith proposed a distinction between two definite categories; individuals whom were poor at both spelling and reading (PRPS), and those that were poorer at spelling than reading (PSGR). In terms of reading ability the PSGR were found to use a logographic technique (by eye) using cues within words such as key letters and shapes, rather than the sound of the word. Consequently, they read for meaning, not sound. This provides clues as to why they are also poor spellers as the letter by letter composition of a word is ignored, instead aiming for a meaning, due to a lack of orthographic knowledge, hence they apply a logographic strategy, whereby new words or those with unpredictable spellings prove greatly difficult.

1.8 The Present Study

The present study aims to investigate further the subcategories of dyslexia as proposed by Frith. Subjects were divided into three groups, controls, dyslexics and dysgraphics enabling us to realise the significance of structural abnormalities in terms of both the subgroups and the influence held by age. Contrary to the previous study by Price (unpublished), we used adult rather than adolescent participants.

The main aims of the study are to determine whether:

1: dyslexic individuals show differences in brain structure, within and across groups.

2: any noted changes are resultant of age, due, for example, to compensatory strategies.

2 Materials and Methods

2.1 Adult Participants

17 adult dyslexics (mean age 21.8; SD 3.8) and 12 adult controls (mean age 26.3; SD 6.01) participated in this study..

The dyslexic subjects had a well documented history of developmental dyslexia, and a clinical diagnosis was provided as evidence for this study. All subjects were physically healthy, absent of neurological disease, head injury and any psychiatric disorder. Only right handed subjects with a first language of English were included. Each subject gave informed consent in accordance with the ethics approval for the study.

2.2 Adolescent study

The structural and behavioural data from 28 adolescent dyslexics (mean age 13.90 years; SD 1.02) and 17 adolescent controls (mean age 14.07; SD1.33) was collected in a previous study. By including the data in the present study we were able to investigate whether group effects interacted with age.

In total, the structural neuroimaging analysis included data from 74 right handed subjects (29 adults and 45 adolescents).

2.3 Psychometric tests

A battery of standardized tests were performed to assess literacy (reading and spelling), phonology and IQ (both verbal and non verbal).

2.3.1 General ability

Assessed via the administration of a full Wechsler adult inventory scale III (WAIS) (Wechsler, 1997), to determine verbal performance and full scale IQ.

2.3.2 Reading

Literary skills were assessed via the Wide Range Achievement (WRAT), The Wechsler Test of Adult Reading (Wtar), the New Adult Reading Test (NART). These tests contain a variety of words from those in common usages (cat), and progress to more complex infrequently used words (pusillanimous).

Also a new test based upon the principles of Homophones and Synonyms was developed and we refer to this test as HOMSYN. The test comprises of 27 synonyms and 24 homophones. The reading test was administered first, with each word presented individually using a MATLAB program. Participants were asked to read aloud each word and then press a key to forward to the next word.

2.3.3 Spelling

A battery of similar tests were performed to assess spelling ability. These included HOMSYN, Wide Range Achievement Test and the Graded Difficulty Spelling Test. All spellings were read to the participants in the context of a sentence with the participant recording answers on specially formulated scripts. For example: "The boy cried with pain when he was hit by the ball. "PAIN". The participant then wrote down the word "PAIN".

A self report questionnaire was performed after the Graded Difficulty Spelling Test. The aim of this questionnaire was to ascertain possible methods by which the participants remembered the spellings (sound or visual appearance).

2.3.4 Word recognition tasks

Specially constructed lists of words (reading tasks as above) and non words (pseudo words comprising of 40 spoken words for repetition, and 20 spoken words for spelling) were presented on the computer screen with naming latencies recorded via the use of MATLAB. The nonword test is important in that it offers the ability to assess the individual's grapheme to phoneme processing skills. The repetition in particular of nonwords is an important assessor of auditory processing and short term phonological memory.

2.3.5 Phonological awareness

The Phonological Assessment battery (phAB) (Fredrickson, Frith and Reason, 1997) was performed involving timed exercises of picture and digit naming, to assess the ability to access phonological knowledge at speed.
Next the Spoonerism task was used to assess individual capability for manipulation and phonological segmentation of 12 paired stimuli.

All of the above tests were performed in concordance to their specific guidelines and any test which involved a spoken response was digitally recorded for the results to be checked by a separate marker. It should be mentioned that in relation to complex less common word reading and spelling, performance is naturally dependent upon incidental learning and hence will depend upon an individuals history of exposure to such words. All tests conducted were referred to as paper and pencil tests and a complete test package including the recording sheets can be seen in appendix 1.

2.4 MRI Scanning procedure

Structural Scan

To assess structural differences using a whole brain unbiased objective technique, voxel based morphology (VBM). A whole structural MRI scan was acquired from all subjects using a 3D T1* weighted sequence (1x1x1.5mm voxel size) on a 1.5 tesla magnetron vision scanner, using a whole body coil for RF transmission and an 8 element phased array head coil for signal reception, scans were acquired using a modified Driven Fourier Transform (MDEFT) sequence (Ugurbil et al, 1993). Two fold oversampling was performed in reading direction (head/foot direction) to prevent aliasing, with an isotopic resolution of 1mm. Subjects were instructed to perform minimal movement and visual images were presented on an overhead screen to aid relaxation.

2.5 Behavioural Data analysis

The literacy impaired group were subdivided into two groups based upon spelling and reading ability.

Group 1- Dysgraphics (poor spelling but good reading)

Group 2- Dyslexics (equally poor reading and spelling)

Dyslexics had more difficulty with reading than spelling; dysgraphics had more difficulty with spelling than reading. These subdivisions were calculated in the following steps. First we found the mean for spelling and the mean for reading, based on the whole sample, irrespective of group. Then we calculated the mean centred values by subtracting the mean for each raw score. The difference between reading and spelling was based on differences in the mean-centred score. A negative score indicates an individual who is better at spelling than reading (relative to the group) and was hence dyslexic, with dysgraphics obtaining a positive score indicating they are better at reading than spelling.

SPSS was used to analyse the behavioural tests. This involved a multivariate ANOVA (MANOVA) using a general linear model with the significance threshold set at $P<0.05$, the group (dyslexics, dysgraphics and controls) were the independent variable and the behavioural measures were the dependent variable, highlighting any significant differences between groups. Three subtest groups will be used and analysed in terms of correlation and regression.

These subsets are as follows:

- By eye/perceptual organization (including picture completion, arrangement and block design)
- By ear/phonetic (including spoonerisms and nonword repetition)
- Semantic (which includes semantic information, vocabulary and similarities.

These subset categories will then each be correlated with reading and spelling ability for the three original groups (dyslexic, control and dysgraphic).

2.6 MRI Data Analysis

Adolescent data from the previous study by Price et al., 2005 (unpublished) will be analysed alongside the adult data, with both age ranges divided into subgroups for this purpose.

2.6.1 Pre-Processing

Statistical parametric mapping (SPM5: Wellcome Department of Imaging Neuroscience, London, UK, http//www.fil.ion.ucl.ac.uk) running under MATLAB 6.5.1 (Mathworks, Sherbon, MA, USA) was used for imaging processing and statistical analysis.

All subject volumes were segmented into grey and white matter and spatially normalised into stereotactic space to enable cross subject comparison. Structural images had a final voxel size of 1.5x1.5x1.5mm, segmented into grey, white and CSF compartments, smoothed with an 8mm isotopic Gaussian kernel. After smoothing each voxel will represent the local average amount of grey matter in the size of the region, the size of which is defined by the size of the smoothing kernel.

2.6.2 Structural Analysis

Six groups in total were modelled, adult dyslexics, adult dysgraphics and adult controls, with the same for the adolescent group. This data was analysed using SPM5 employing a framework of the general linear model, the groups were compared using a two sample T test to indicate regionally specific structural differences in grey matter, with a significance level set at $P<0.05$ for multiple comparisons.

Whole brain analysis of grey matter density was used to reveal similarities and differences between dyslexics and dysgraphics, with direct comparisons made between categories in the same age range and between age ranges. A comparison between subgroups and the control group was also made. The purpose of these comparisons was to indicate the regional abnormality in a subgroup related to the regional normality in controls, whilst also revealing shared abnormalities between the two groups relative to controls.

A comparison between adult and adolescent data was necessary in order to assess the consistency of the findings, ultimately indicating whether differences between groups were dependent on age.

3 Results

3.1 Behavioural results

The behavioural data included in this project is from the adult group only, as adolescent data was collected in a previous study (for Adolescent data please see appendix 2). The adult data has been divided into three groups: controls dyslexics, and dysgraphics. The control group had no history of difficulty learning to read. The dyslexics and dysgraphics both had a diagnosis of dyslexia. The division of groups was based on their relative reading and spelling ability in accordance with Friths (1975) subgroups. Dyslexics had more difficulty with reading than spelling; dysgraphics had more difficulty with spelling than reading. These subdivisions were calculated in the following steps. First we found the mean for spelling and the mean for reading, based on the whole sample, irrespective of group. Then we calculated the mean centred values by subtracting the mean for each raw score. The difference between reading and spelling was based on differences in the mean-centred score. A negative score indicates an individual who is better at spelling than reading relative to the group and was hence dyslexic, with dysgraphics obtaining a positive score indicating they are better at reading than spelling. (All raw scores can also be seen within appendix 2).

	Controls	SD	Full Sample	SD	Dysgraphics	SD	Dyslexic	SD
Age (years)	24.70	*3.2*	23.10	*4.10*	24.20	*4.40*	22.00	*3.90*
Full IQ	118.83	*11.97*	112.31	*9.66*	113.71	*7.23*	110.67	*12.45*
Verbal IQ	118.67	*9.67*	110.23	*7.65*	110.86	*7.47*	109.50	*8.50*
Performance IQ	115.17	*11.67*	113.31	*12.62*	115.86	*9.08*	110.33	*16.23*
Digit Span	20.33	*4.13*	15.31	*4.03*	15.29	*3.90*	15.33	*4.54*
SPELLING								
HOMSYN								
Total *	95.00	*7.54*	80.77	*11.50*	79.57	*14.52*	82.17	*8.81*
Synonym	51.67	*3.20*	46.15	*5.38*	45.43	*6.60*	47.00	*4.34*
Homophone	43.33	*4.97*	34.62	*6.49*	34.14	*8.31*	35.17	*4.83*
WRAT **	32.83	*2.31*	25.92	*6.05*	23.14	*5.77*	29.17	*4.79*
Graded Difficulty *	25.84	*2.93*	18.62	*4.97*	17.00	*5.09*	20.50	*4.81*
Nonword **	10.46	*2.94*	5.85	*1.88*	5.29	*0.82*	6.50	*2.51*
READING								
HOMSYN								
Total	101.33	*1.03*	99.46	*5.85*	98.57	*8.42*	100.50	*1.05*
Synonym	53.67	*0.52*	53.00	*2.54*	52.57	*3.61*	53.50	*0.55*
Homophone	47.67	*0.52*	46.47	*3.40*	46.00	*4.83*	47.00	*1.10*
WRAT *	40.12	*5.16*	33.92	*5.32*	34.57	*5.75*	33.17	*5.27*
WRAT RT (ms)*	1431.05	*482.33*	2205.47	*824.44*	2438.61	*1031.22*	2136.57	*599.26*
WTAR	43.17	*5.87*	37.31	*8.06*	37.14	*7.34*	37.50	*9.40*
WTAR RT (ms)*	1507	*452.58*	2561.00	*851.99*	2731.00	*858.98*	2401.00	*943.61*
NART **	44.71	*7.67*	31.23	*7.19*	32.43	*6.41*	29.33	*8.40*
NART RT (ms)**	1437.23	*581.93*	2820.74	*768.31*	2969.00	*686.00*	2795.00	*938.54*
Nonword (NW)	22.83	*2.23*	20.77	*4.30*	20.29	*5.05*	21.33	*3.83*
*NW RT(ms)***	1218.26	*394.81*	2326.41	*665.66*	2516.36	*697.25*	2098.47	*617.23*
PhAB								
PICTURES								
1.00	49.83	*0.41*	49.85	*0.39*	49.71	*0.52*	50.00	*0.00*
2.00	49.38	*1.21*	49.92	*0.29*	50.00	*0.00*	49.83	*0.41*
Picture RT	35166.08	*4377.39*	32815.50	*9095.16*	34426.36	*11162.42*	30936.17	*6689.48*
DIGITS								
1.00	50.00	*0.00*	49.62	*0.67*	49.86	*0.41*	49.33	*0.82*
2.00	49.83	*0.41*	49.54	*1.00*	49.57	*0.84*	49.50	*1.22*
Digit RT	18680.42	*3000.40*	23488.89	*18289.97*	27023.86	*22615.65*	19364.75	*12252.13*
PHONETIC								
Spoonerisms	19.67	*3.56*	17.08	*7.35*	15.43	*9.61*	19.00	*3.90*
Non-word Rep	33.17	*3.37*	30.08	*6.13*	30.86	*4.36*	29.17	*7.96*

Table 1. Summary of behavioral Data, standard deviations are indicated.

Results are given as actual scores and rounded to 2 decimal places.

Significances is indicated by the presence of * for 0.05, ** 0.01 and *** for 0.001 significance levels. In relation to controls a significant difference was noted when compared to dyslexics and dysgraphics, but no significant difference was obtained between the dyslexic and dysgraphic subgroups.

The groups in general were well matched for age and IQ, with the recorded IQ's above average (110-125 is above average) as can be seen in Table 1. Overall the control group performed better on the reading and spelling tasks. There was also a trend for dysgraphics to have worse spelling and slower reading than the dyslexics but this difference did not reach significance. This is an important observation because it illustrates how our subgrouping are not based on the performance on individual scores but on differences in relative scores. Thus a dysgraphic is defined as someone who had better reading than spelling but this definition includes those with severely impaired spelling or mildly impaired spelling. Likewise, a dyslexic is defined as someone who had better spelling than reading but this definition includes those with severely impaired reading or mildly impaired reading.

3.1.1 MANOVA

The source of any difference is investigated using tests of between subject and within subject effects produced by Multivariate ANOVA. In total ten main effects for adult data was noted which will be separated into reading and spelling scores and reading times.

3.2 Adult Data

3.2.1 Spelling data

Both the dyslexic and the dysgraphic groups were less accurate in spelling in relation to the controls, both together and separately, although no significance is noted between just the dyslexic and dysgraphic sub-groups.

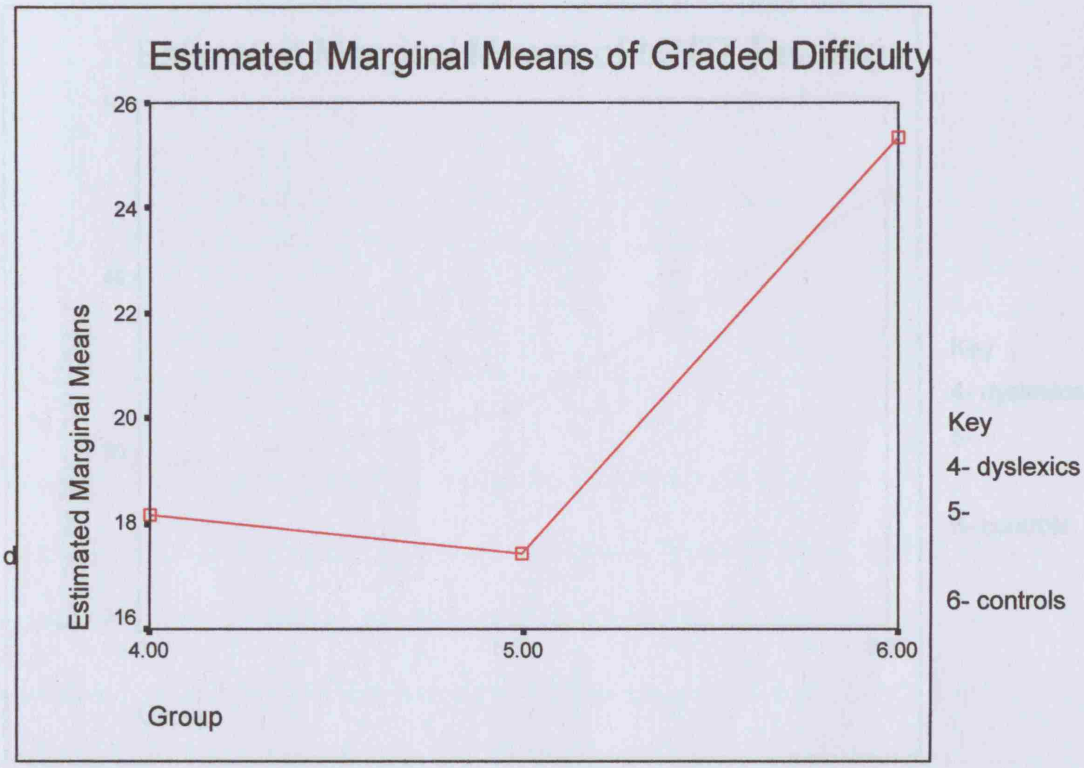


Figure 2: Marginal means of adult Graded difficulty spelling scores. The Graded Difficulty Spelling test produced significant results whereby the adult controls score better than both the dyslexics and the dysgraphics ($F(2,16)= 5.57$, $P<0.05$). For WRAT spelling ($F(2,16)= 6.95$, $P<0.01$) adult controls were significantly more accurate than the adult dysgraphics.

3.2.2 Reading Data Scores

Both the dyslexic and dysgraphic groups were significantly less accurate, obtaining lower scores than the control group; they are also significantly slower in task completion than the controls, although no significant difference is present between the dyslexic and dysgraphic subgroups.

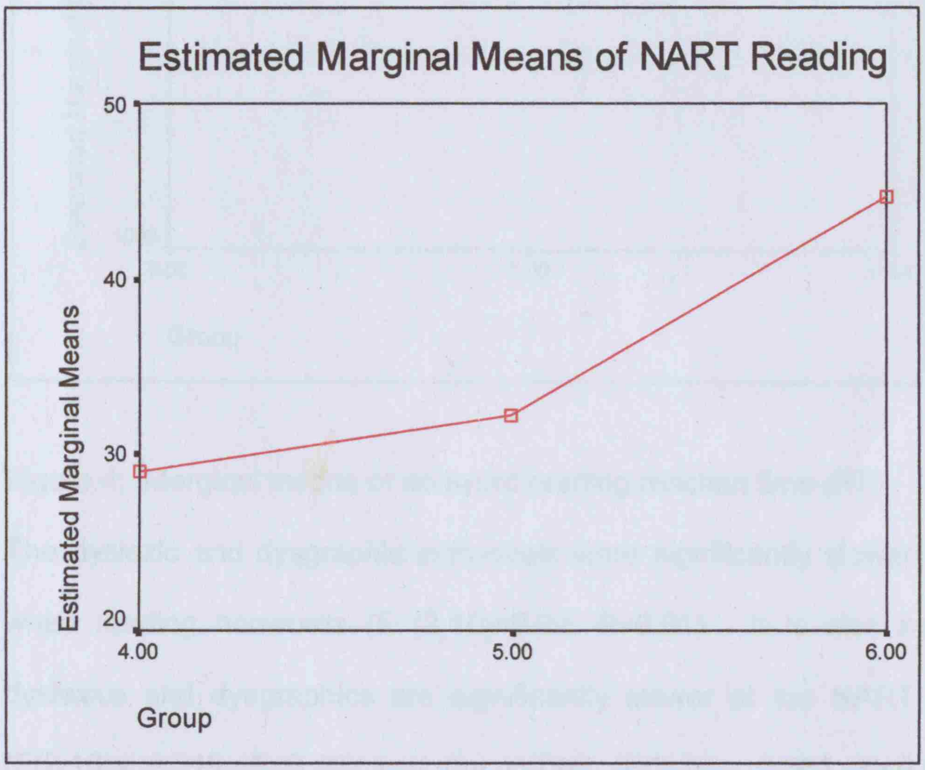


Figure 3: Marginal means of NART reading scores. In terms of reading controls generally performed better, producing a significantly better score on the NART assessment ($F\ (2,16) = 8.37$, $P<0.01$) in relation to both dyslexics and dysgraphics. It was also noted that controls had a significantly better performance on the WRAT reading ($F\ (2,16) = 4.30$, $P<0.05$) than the adult dyslexic groups.

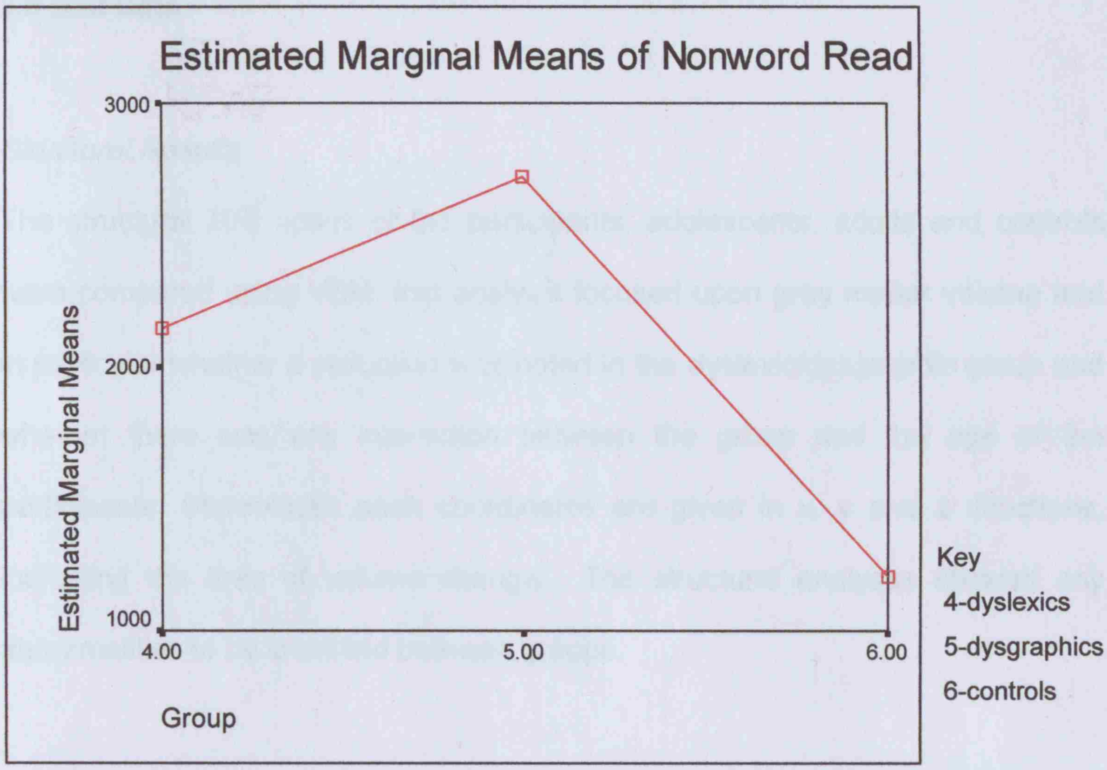


Figure 4: Marginal means of nonword reading reaction time (RT).

The dyslexic and dysgraphic individuals were significantly slower than controls when reading nonwords ($F(2,16)=9.89$, $P<0.01$). It is also noted that the dyslexics and dysgraphics are significantly slower at the NART reading task ($F(2,16)= 8.318$, $P<0.05$) and the WTAR ($F(2,16)= 5.683$, $P<0.05$) than the controls.

3.3 MRI Data

Structural Results

The structural MRI scans of the participants, adolescents, adults and controls were compared using VBM, this analysis focused upon grey matter volume and in particular whether a reduction was noted in the dyslexic/dysgraphic group and whether there was any interaction between the group and the age of the participants. Stereotactic peak coordinates are given in x, y and z directions, indicating the area of volume change. The structural analyses allowed any abnormalities to be identified between groups.

3.3.1 Regions of Interest

On the basis of a previous study of adolescent participants, we predicted that dyslexic and dysgraphic participants would show significant differences in grey matter of the midline cerebellar region where grey matter previously correlated with the difference between reading and spelling scores. i.e. grey matter was lowest when spelling was worse than reading, see Figure 5 and Table 2 for details

Figure 5: Regions of interest from previous study of adolescent participants.

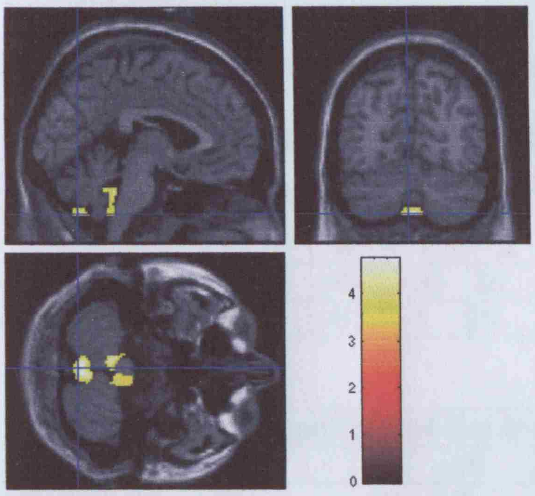


Table 2: Regions of interest from previous study of adolescent participants.

Anatomical region	Co-ordinates X	Y	Z	Z score	Voxels	P-value
Midline cerebellum	-2	-70	-50	4.2	165	0.002
	-4	-42	-34	4.0	374	0.000

The comparison of relative grey matter density in dyslexics, dysgraphics and controls revealed three different effects:

1) In the left supramarginal gyrus and left premotor cortex, grey matter was less for both dyslexics and dysgraphics relative to controls (see Table 3a and Figure 6a)
2) In the right premotor, postcentral and superior parietal cortices, and also the left occipito-temporal gyrus, there was less grey matter for dyslexics than controls or dysgraphics (see Table 3b and Figure 6b).

3) In the midline cerebellum, our region of interest, there was less grey matter for dysgraphics than controls or dyslexics (see Table 3c and Figure 6c).

Table 3: Details of results from analysis of grey matter.

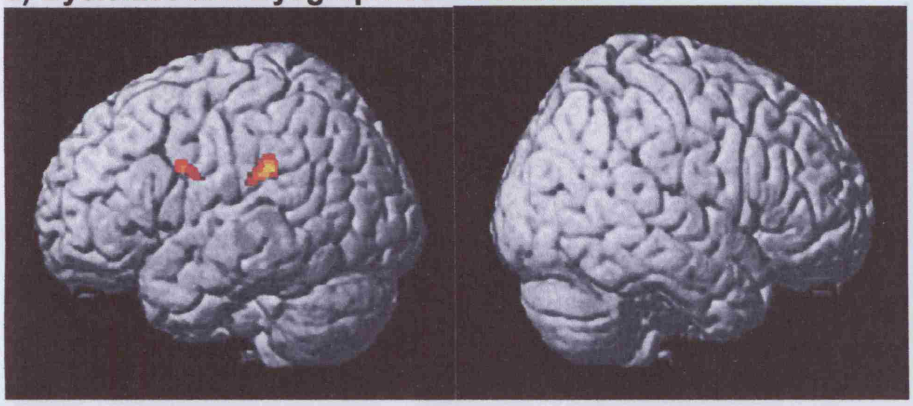
a: Dyslexics and Dysgraphics < Controls

Anatomical region	Co-ordinates X	Y	Z	Z score All	Number of Voxels	Z scores Adol/Adult
Left supramaginal gyrus	-64	-36	26	4.3	106	2.6/3.7
Left premotor region	-62	-4	28	3.6	49	3.3/3.8
b: Dyslexics < Dysgraphics and Controls						
Right postcentral gyrus	66	-16	20	4.9	59	2.4/4.7
Right premotor area	52	2	44	4.4	126	3.2/3.7
Right superior parietal gyrus	38	-50	64	4.5	105	3.4/3.9
Left occipito-temporal lobe	-46	-84	-14	4.7	233	3.0/3.9
c: Dysgraphics < Dyslexics and Controls						
Right midline cerebellum	10	-60	-48	3.6	46	4.0/2.7

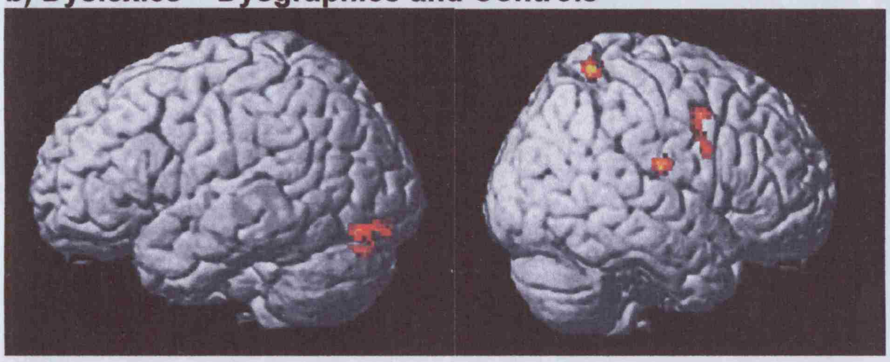
All = all subjects, Adol = adolescents from previous study, Adul = adults from new study.

Figure 6: Illustration of results from analysis of grey matter.

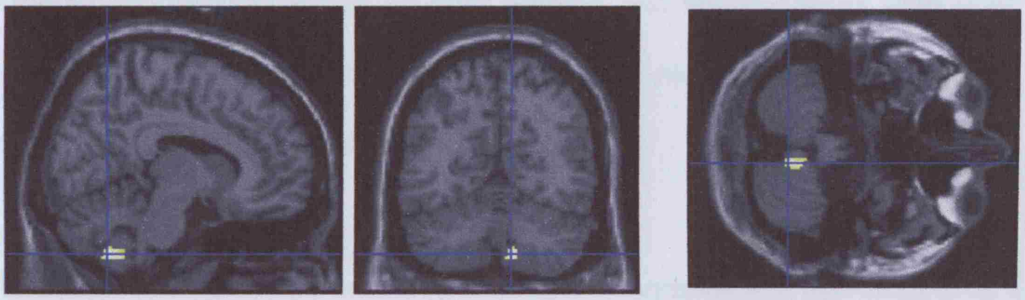
a) Dyslexics and Dysgraphics < Controls



b) Dyslexics < Dysgraphics and Controls



c) Dysgraphics < Dyslexics and Controls



Reduced grey matter is indicated in colour on 3D models of the left and right hemisphere (a and b), or 3D sections centred on the peak co-ordinates of the effect (c), see Table 3 for details.

4 Discussion

The main aim of this study was to determine whether behavioural and structural imaging findings would offer any insights into subcategories of dyslexia.

4.1 Behavioural findings

Analysis of behavioural data revealed significant differences between control subjects and those with reading and spelling difficulties.

Overall the control group was seen to perform significantly better than both dyslexics and dysgraphics. All subjects were well matched for age, IQ and handedness (only right handed individuals were included within the study).

4.1.1Reading and spelling

Reading and spelling are important, in that dyslexics and dysgraphics in general performed significantly worse on both reading and spelling tasks than controls. Also due to matched IQ and age it is possible to infer that these differences are not down to educational attainment.

In terms of reading scores both dyslexics and dysgraphics performed worse than their control counterparts, consistent with their diagnosis of dyslexia (Ramus et al, 2003.; Frith, 1975,; Chiappe et al, 2002). In particular, nonword reading times were significantly slower in both dyslexic and dysgraphic subgroups. This suggests that, despite well compensated reading abilities, the dyslexics and dysgraphics still have difficulties generating a novel phonological representation to unfamiliar letter strings. This is consistent with a deficit in the application of grapheme-phoneme correspondence rules (Frith, 1975). However, it should also be noted that the reading problems were not limited to novel words, the dyslexics and dysgraphics were also slower and less accurate reading familiar words with unusual spellings (as indicated by the NART and WTAR tests).

Both the WTAR and the NART tests contain exception words, that is they do not have consistent spellings as regular words do, and it is often seen that certain dyslexics may infact have a greater difficulty with these words due to a deficit in the lexical processing system used to identify these exception words (Price and Mechalli, 2005). Previous studies have made a distinction between surface and phonological developmental dyslexia (Castles et al, 1999). The surface dyslexics have more difficulty with words that have exceptional spellings, with the phonological dyslexics having greater difficulty with non-words. In future analyses, we could re-group our subjects in terms of their relative ability on reading different word types. However, this was not the basis for the present project.

Overall it can be seen that the difficulty experienced by dyslexic and dysgraphics is as a result of a failure within analysing the sound structure of language, which in turn results in a failure to learn systematic relationships between spelling and sounds (phonological) whilst at the same time an inability to adapt rules in order to read and spell exception words and pseudowords.

It is important to note that within this study no significant differences were presented on pure phonological assessment tasks and hence it is not possible on the basis of the collected data to infer whether the problems encountered with the dyslexics and the dysgraphics are as a direct result of phonological deficit or any other deficit. This may be as a result of compensation with support offered by the previous adolescent study (Price et al, unpublished) whereby dyslexics did indeed show significantly worse phonological ability compared to the dysgraphics.

Hence the collected behavioural data is inconclusive as to why differences are noted between the control and dyslexic/dysgraphic individuals. It is important to look at the structural data in order to see if any higher order effects can be noted in accordance with the aims.

4.2 Structural Imaging Findings

Consistent with our hypotheses, analysis of the structural MRI scans revealed relative grey matter reductions in the midline cerebellum for dysgraphics relative to both dyslexics and controls. In addition, the adult data revealed that all dyslexics and dysgraphics have reduced grey matter in areas associated with the left hemisphere 'phonological loop' (left supramarginal and left premotor gyri), with a corresponding reduction in the right hemisphere for dyslexics relative to controls and dysgraphics. The adult data therefore revealed a double dissociation between dyslexics and dysgraphics. By combining the adult and adolescent data, we were also able to show that the observed effects did not depend on the age of the participants. To the contrary, the grey matter differences with reading and spelling ability were consistent for adult and adolescent participants.

4.2.1 Grey Matter Differences in the Midline Cerebellum

A significant decrease in grey matter volume was noted within the right midline cerebellum for dysgraphics compared to both dyslexics and controls. This finding is consistent with many that implicate cerebellar dysfunction with poor reading (Nicolson and Fawcett, 1996, Rea et al, 2002). However, by using small voxels (2mm^3) rather than large volumes of interest, our results show, for the first time, the exact cerebellar region rather than a general level of deformity (Leonard et al, 2001,; Rea et al, 2002). We also show for the first time that the cerebellar abnormality is driven by a subset of participants who have worse spelling than reading.

At present the precise function of the cerebellar region we identified remains unclear. This could be investigated by functional imaging studies that compare neuronal activation for reading and spelling. Our region of interest, at the base of the cerebellum indicates where functional imaging data needs to be acquired. This is important because many functional imaging studies use a limited field of view to increase sensitivity in areas of interest. As the base of the cerebellum is not typically a region of interest in reading and spelling studies there is currently very little data to provide evidence for its function. Nevertheless, one functional imaging study of dyslexic participants suggested reduced activation for dyslexics during motor learning tasks (Nicolson et al, 1999). On the basis of our structural imaging results, future studies could investigate whether spelling ability was correlated with motor learning deficits.

Previous studies have also suggested that a reduction in cerebellar grey matter is corrected with age (Nicolson et al, 1999,; Lee et al, 2005), and IQ. In our studies, we controlled for IQ and systematically manipulated the age of the subjects (adolescent vs adult). Although we found substantial grey matter differences in the cerebellum according to the age of the subjects, the age of the subject did not interact with spelling and reading difficulty. This suggests that age, IQ, spelling and reading ability affect cerebellar grey matter in independent ways.

It is also important to note that the structural differences we observed in the cerebellum can not be interpreted as the cause of dyslexia because they may simply reflect differences in reading and spelling experience. Changes within the grey matter may also have been induced by training (Draganski et al, 2004) or indeed a compensatory mechanism.

4.2.2 Reduced Grey Matter in the Left hemisphere for dyslexics and dysgraphics

A significant decrease in grey matter for both dyslexics and dysgraphics relative to controls was noted in two areas of the left hemisphere phonological loop. Firstly within the left supra marginal gyrus and secondly within the left premotor region. Both of the above areas are indicated by functional imaging studies to have similar functions, that is they are both activated when an individual makes any level of phonological decision over a semantic one (As reviewed in Price and Mechalli, 2005), and were associated with the "phonological loop" in one of the earliest imaging studies (Paulesu, Frith, Frackowiak, Nature 1993). Thus deficits within these areas may offer possible support for the phonological theory of dyslexia.

The reduction of grey matter in areas associated with the phonological loop is an important finding in terms of the phonological deficit model, as the phonological loop is used to rehearse verbal information and keep it within the short term memory, a reduction in the grey matter here may infact reduce the ability of an individual to hold the information within their short term memory and hence their level of decay may be much faster than someone without this deficit.

Surprisingly, however, our behavioural data did not reveal significant differences in the phonological abilities of any of our three adult groups (controls, dyslexics, dysgraphics) although the adolescent dyslexics had significantly reduced phonological abilities relative to the controls and dysgraphics (as predicted by Frith et al. 1980). The lack of significant differences in the adult sample is likely to reflect the considerable variance in phonological abilities within the adult groups. As the dyslexic sample were extremely well compensated, they may have had considerably more practice performing phonological tasks which would have improved their ability and lessened the behavioural difference relative to control subjects. Nevertheless, the structural neuroimaging data suggest that, despite their good performance, there was still a reduction in grey matter in the phonological loop. This inconsistency between behavioural and imaging results suggests that the dyslexics might have learnt to perform the phonological processing tasks by engaging different brain regions. Functional imaging data on the same participants during phonological processing tasks could assess whether this prediction was true or not.

According to the early behavioural studies by Frith (1980), dyslexic children have poorer phonological skills than dysgraphics. Hence, we might have expected to see less grey matter in the phonological loop for dyslexics relative to dysgraphics. Although this hypothesis was not confirmed in the left hemisphere, the dyslexics but not the dysgraphics showed reduced grey matter in right hemisphere phonological regions (see next section).

4.2.3 Reduced Grey Matter in the Right Hemisphere

Despite well compensated phonological abilities, the dyslexic group showed reduced grey matter in right, as well as left regions associated with phonological processing. In other words, the dyslexics had grey matter reductions in bilateral regions associated with the phonological processing whereas the dysgraphics were only affected in the left hemisphere. The greater loss in phonological regions for dyslexics than dysgraphics is consistent with the theories of Frith (1980) even though some of our dyslexics had well compensated phonological abilities.

In this study, we only had time to investigate differences between different groups of dyslexics. However, using the same data set, we should also be able to investigate how grey matter density is affected by phonological abilities. For example, the grey matter loss we currently associate with reading and spelling difficulties might be better explained by phonological abilities. In other words, there might be less grey matter in the phonological loop for dyslexics with poor phonological abilities.

The locations of areas affected in our dyslexic sample were not identical in the left and right hemispheres. In the right hemisphere, there was reduced grey matter in the postcentral gyrus and also the superior parietal cortex. The postcentral gyrus is an important somatosensory region, a reduction in grey matter within this area may indeed implicate that within the dyslexic individuals it is not simply a phonological deficit that is incurred but rather a more general somato-sensory deficit instead, this is further supported by the fact that a decreased grey matter density is located within the right superior parietal area. A disruption within this area can also cause visual problems and hence may be suggestive of a visual deficit in certain types of dyslexics. Further, functional and structural imaging studies are required to investigate these effects.

4.2.4 Reduced grey matter in the left occipito-temporal cortex for dyslexics.

In addition to the reduced grey matter in the right hemisphere, dyslexics also had reduced grey matter in the left occipito-temporal cortex in comparison to both dysgraphics and controls. The left occipito-temporal region we identified is posterior to that associated with dyslexia in other structural and functional imaging studies (see Silani et al. 2005). It is closer to the visual motion processing areas that have been reported to be dysfunctional in other studies of dyslexia (G.F. Eden 1993, 1994). Our result suggest that such deficits may be particular to the dyslexic rather than dysgraphic subgroups. It also highlights the heterogeneous problems associated with dyslexia.

4.3 Limitations

Although the aim of this study was to minimise any possible limitations certain problems remain. Most importantly, as in all other structural and functional imaging studies of developmental dyslexia, it is not possible to distinguish between cause and effect; therefore it is impossible to determine the origin of the structural abnormality. In the broad sense this means that any structural abnormality could be the result of physiological problems in the affected area or as a consequence of a lack of experience in regard to reading and spelling, due to a learning deficit that is not specific to the affected regions.

A second limitation is that we forced our data into three different groups (controls, dyslexics and dysgraphics) even though there was a continuum present in their reading and spelling abilities. Hence two subjects may be very close in literary deficit but fall into different subgroups, which may reduce our sensitivity to other affects.

This may explain why insignificant effects were noted between dyslexics and dysgraphics in relation to behavioural tasks. Another contributory factor here is that many of the dyslexic subjects were familiar with certain tasks because of previous assessments for dyslexia. Their scores on our measurements (e.g. WAIS intelligence assessment battery) may therefore have been inflated.

A third limitation relates to our inability to distinguish subjects who have mild dyslexic symptoms from those who have well compensated abilities. The main basis of the definition of what constitutes a dyslexic and a dysgraphic was down to their performance on both reading and spelling tasks, but both of these tasks are reliant upon incidental learning and overall experience. Therefore an individual's performance may be better than expected if they are avid readers and hence more familiar with a wide variety of words. In the adult study, we only included high achieving adult dyslexics who were university students. Again, this may have decreased our sensitivity to effects and prohibits generalisations to the wider dyslexic population. Although in defence it is prudent to note that our aim was not to establish the overall incidence of the subgroups but instead the neural networks and behavioural factors that exist between groups.

4.4 Conclusion

In conclusion it can be seen that within our study significant structural differences were noted between dyslexic, dysgraphic and control individuals independent of age. Both the dyslexic and dysgraphic groups had reduced grey matter, relative to controls in left hemisphere regions associated with the "phonological loop". This finding is consistent with previous behavioural data showing that phonological deficits are the most consistent behavioural manifestation of reading impairments. Critically, however, our results also highlight a double dissociation in the brain structure of dyslexics and dysgraphics. Dyslexics had reduced grey matter in right hemisphere areas associated with phonology whereas dysgraphics had reduced grey matter in the cerebellum.

It is important to note that the double dissociation in brain structure could not be predicted on the basis of individual behavioural scores. Thus, there was no significant difference between either reading or spelling in the dyslexic vs dysgraphic groups. The behavioural dissociation was only observed in the relationship between reading and spelling performance. In other words it was a higher order behavioural manifestation that was only revealed after examination of the variance driving abnormalities in brain structure.

Finally it is important to realise that the observed structural differences cannot be interpreted as the cause of dyslexia because structural brain differences may also reflect different types of experience with reading and spelling. With respect to the cause of dyslexia, it is becoming increasingly clear that dyslexia is caused by genetic influences (Fisher and Francks, TICS 2006) but as yet, there is no clear link between the four different candidate dyslexia genes and the behavioural manifestation. Future structural imaging studies may provide the link between genetics and behaviour. For example, on the basis of the current results, future studies could determine whether the dyslexics and dysgraphics have different genetic makeups. In conclusion, although neuroimaging does not reveal the cause of dyslexia, it can be used to guide future genetic studies and may also influence the type of therapy that is required to compensate for reading difficulties.

4.5 Future Work

Future work has been considered within the discussion section but a summary of the major points can be seen below.

As a result of the stated limitations, it may be important to replicate these findings in a larger and more varied cohort of dyslexic individuals, with more in-depth behavioural tests so that subgroups can be clearly defined.

Although it is very difficult to resolve the issue of cause or consequence, a functional study run in parallel would provide a useful link between structure and behaviour, although a genetic study also would provide relevant information helping to develop a causal explanation for the disorder.

Also this study has only noted changes within grey matter, hence an extension could be to analyse white matter as well. This is due to white matters previous implication in dyslexia by many studies (klingberg et al, 2000: Silani et al, 2005: Beaulieu et al, 2005).

Importantly as previously indicated structural studies are not able to produce a causal model for this disorder and hence the integration of this study, with genetic, social and behavioural investigations will lead us closer to a definitive cause and hypothesis for development dyslexia, which overall is the ultimate aim.

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Appendix 1

Spelling responses for HOMSYN

S 1

The ________________ is in the________________.

The ________________to the question is a ________________.

The ____________is now in ______________.

The ________________ took many________________.

The ________________ was ________________from the boat.

Welcome to my humble ______________.

The______________ was a ________________ to the__________.

The ______________ was ________________with the teacher.

Sad ______________ make you________________.

The ______________ scared the ______________.

The ______________ sang beautifully.

The ________________was given an ____________of flowers.

The ________________ stayed at the hotel.

Jane wanted a ______________to what her present was.

The ________________was empty of water.

A friend is the opposite of a ______________.

H 1

The ________________ stalked its______________.

The ________________felt was cold.

The _________________was ______________pounds.

The __________________was long.

The man flexed his________________.

Bread is made from _________________.

To __________________your __________________is painful.

Mark bought a ________________ table in the__________________.

The disc stored one ____________________of information.

The old _________________was ______________ into the skip.

The ________________of glass was broken.

The boat arrived in the_______________.

The ________________loved to eat __________________.

Jane was ________________staying in.

The __________________man streaked across the pitch.

The ___________________number was scanned.

Jane thought ________________when alone.

After Christmas Janet did not __________________ herself.

S2

The ______________ was ______________ from the _________.

The ______________ played with a ______________.

The ______________ was in the ______________.

The ______________ sang in the ______________.

The ______________ was sent to ______________.

The ______________ of the ____________ was incurred.

The girls' ____________ ripped, making her ____________.

The witch cursed the __________ of her ____________.

The disappearance was an ____________.

The cinema shows the latest ____________.

The ______________ was a ____________.

A ______________ was needed to ______________.

The ______________ took the __________ not the __________.

The ______________ was head of the monarchy.

H2

The boy was not _____________ sweets.

The girl ____________ _____________ for breakfast.

The _____________ washed up on the _____________.

The _____________ ____________his chest.

The crew was on ____________ ready to _____________.

The _____________on the car failed.

A ______________ is a female deer.

There was a ______________ for the army

After one ____________ the ____________ was ____________.

A ______________ was given to respond.

The weather is _____________.

The ____________ fitted the lock.

The boy _____________ the ____________ between points.

The patients who are in ___________ ____________.

The queen sits on her ____________.

A map helps find the ____________.

WRAT Spelling

	RESPONSE	SURE?
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

21		
22		
23		
24		
25		
26		
27		
28		
29		
30		
31		
32		
33		
34		
35		
36		
37		
38		
39		
40		

Graded Difficulty Spelling Test

	RESPONSE	SURE?
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		
26		
27		
28		
29		
30		

Self Report Questionnaire (after graded difficulty spelling test).

How did you remember the spelling?

Did you think what it looked like?

Did you think what it sounded like?

Any other strategies or comments you feel would be helpful?

Spelling Nonsense Words

Spelling	Sure?
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

Reading HOMSYN

VOICE RECORDER ON ?

Word	Correct x/√	Word	Correct x/√
Absent		Allowed	
Baby		Ate	
Bucket		Beach	
Cargo		Bear	
Child		Beat	
Choir		Bite	
Criminal		Board	
Cry		Brake	
Devil		Cereal	
Dress		Cue	
Dwelling		Doe	
Enemy		Draft	
Enigma		Fair	
Films		Foul	
Gift		Key	
Hint		Knows	
King		Links	
Lift		Mussel	
Lobby		Pain	
Prison		Pray	
Reply		Sail	
Stairs		Sweet	
Student		Throne	
Trip		way	
Vase			
Visitor			
Wrath			

Go to page 2!

Reading HOMSYN cont

Word	Correct x/√	Word	Correct x/√
Aloud		Missing	
Eight		Infant	
Beech		Pail	
Bare		Freight	
Beet		Kid	
Byte		Chorus	
Bored		Felon	
Break		Weep	
Serial		Demon	
Queue		Frock	
Dough		Abode	
Draught		Foe	
Fare		Mystery	
Fowl		Movies	
Quay		Present	
Nose		Clue	
Lynx		Monarch	
Muscle		Elevator	
Pane		Foyer	
Prey		Jail	
Sale		Answer	
Suite		Steps	
Thrown		Pupil	
weigh		Journey	
		Urn	
		Guest	
		Anger	

SCORE

Reading from WRAT (Wide Range Achievement Test)

VOICE RECORDER ON ?

WORD	CORRECT	WORD	CORRECT
In		Bibliography	
Cat		Horizon	
Book		Municipal	
Tree		Unanimous	
How		Benign	
Animal		Discretionary	
Even		Stratagem	
Spell		Seismograph	
Finger		Heresy	
Size		Itinerary	
Felt		Usurp	
Split		Irascible	
Lame		Pseudonym	
Stretch		Oligarchy	
Bulk		Covetousness	
Abuse		Heinous	
Contemporary		Egregious	
Collapse		Omniscient	
Contagious		Assuage	
Triumph		Disingenuous	
Alcove		Terpsichorean	

SCORE

Reading from WTAR (Weschsler Test Of Adult Reading)

VOICE RECORDER ON ?

Word	Correct x/√	Word	Correct x/√
Again		Conscientious	
Address		Homily	
Cough		Malady	
Preview		Subtle	
Although		Fecund	
Most		Palatable	
Excitement		Menagerie	
Know		Obfuscate	
Plumb		Liaison	
Decorate		Exigency	
Fierce		Xenophobia	
Knead		Ogre	
Aisle		Scurrilous	
Vengeance		Ethereal	
Prestigious		Paradigm	
Wreathe		Perspicuity	
Gnat		Plethora	
Amphitheatre		Lugubrious	
Lieu		Treatise	
Grotesque		Dilettante	
Iridescent		Vertiginous	
Ballet		Ubiquitous	
Equestrian		Hyperbole	
Porpoise		Insouciant	
Aesthetic		Hegemony	

SCORE

Reading from NART (New Adult Reading Test)

VOICE RECORDER ON ?

Word	Correct	Word	Correct	Word	Correct
Ache		Debt		Psalm	
Depot		Chord		Bouquet	
Deny		Capon		Heir	
Aisle		Subtle		Nausea	
Equivocal		Naïve		Thyme	
Courteous		Gaoled		Procreate	
Quadruped		Catacomb		Superfluous	
Radix		Assignate		Gist	
Hiatus		Simile		Rarefy	
Cellist		Zealot		Abstemious	
Gouge		Placebo		Façade	
Aver		Leviathan		Aeon	
Détente		Gauche		Drachm	
Idyll		Beatify		Banal	
Sidereal		Puerperal		Topiary	
Demesne		Campanile		Labile	
Syncope		prelate			

SCORE

Reading Nonwords

VOICE RECORDER ON?

Correct x/√

PRACTICE

feg
wut
hin
mot
kib

TEST

hast

kisp

mosp

drant

prab

sted

gromp

trolb

snid

twesk

tegwop

balras

molsmit

nolcrid

twamket

stansert

hinshink

chamgalp

kipthirm

sloskon

PhAB Pictures

Please mark Errors and tick after complete at end of each run

Picture 1 voice recorder on?		Picture 2 voice recorder on?	
Hat	Hat	Box	Table
Ball	Hat	Table	Ball
Door	Box	Ball	Door
Ball	Door	Hat	Hat
Table	Table	Ball	Box
Ball	Hat	Table	Box
Table	Door	Hat	Hat
Box	Table	Door	Door
Door	Door	Box	Box
Hat	Ball	Door	Ball
Table	Box	Door	Ball
Ball	Door	Hat	Table
Ball	Box	Table	Door
Table	Hat	Ball	Box
Box	Ball	Table	Table
Hat	Ball	Hat	Hat
Box	Hat	Door	Box
Door	Box	Box	Door
Table	Table	Box	Door
Door	Table	Ball	Hat
Hat	Door	Table	Table
Box	Ball	Hat	Ball
Table	Door	Ball	Ball
Box	Hat	Door	Table
Ball	box	Box	Hat

Complete?

Complete?

PhAB DIGITS
Please mark Errors and tick after complete at end of each run

Voice recorder on?

Digits 1

2	8
3	5
9	8
2	1
9	1
5	4
4	5
6	9
3	3
5	2
5	4
5	8
8	4
5	3
2	1
9	8
1	3
5	6
4	5
9	9
1	2
2	8
8	8
5	9
6	6

Complete?

Digits 2

5	4
8	9
8	3
6	5
9	4
2	2
9	6
8	8
5	9
2	2
2	1
4	2
6	4
5	6
1	3
5	8
4	1
9	8
1	4
9	5
3	2
6	9
8	4
4	9
9	6

Complete?

SPOONERISMS

VOICE RECORDER ON ?

Stimuli		Correct Response		Subject Response
basket	lemon	**Lasket**	**Bemon**	
button	turtle	**Tutton**	**Burtle**	
doctor	window	**Woctor**	**Dindow**	
fabric	pocket	**Pabric**	**Focket**	
motor	tiger	**Totor**	**Miger**	
mustard	salad	**Sustard**	**Malad**	
novel	table	**Tovel**	**Nable**	
paper	satin	**Saper**	**Patin**	
rabbit	sofa	**Sabbit**	**Rofa**	
radish	garlic	**Gadish**	**Rarlic**	
razor	medal	**Mazor**	**Redal**	
ribbon	silver	**Sibbon**	**Rilver**	

Nonword Rep

VOICE RECORDER ON ?

Word	Correct
dopelate	
glistering	
pennel	
defermication	
contramponist	
hampent	
reutterpation	
perplisteronk	
blonterstaping	
sepretennial	
detratapillic	
glistow	
frescovent	
bannifer	
stopograttic	
woogalamic	
ballop	
confrantually	
fenneriser	
altupatory	
pristoractional	
underbrantuand	
trumpetine	
sladding	
commeecitate	
tafflest	
loddernapish	
barrazon	
commerine	
empliforvent	
thickery	
voltularity	
versatrationist	
rubid	
brasterer	
diller	
penneriful	
bannow	
prindle	
skiticult	

Appendix 2

Psychometric measures

Variable	*Dyslexics (n=20)*	*Controls (n=14)*	t(32)	p
Age (years)	13.90 (1.02)	14.07 (1.33)	*<1*	*n.s.*
IQ tests (WISC III)				
Full-scale	102 (23.98)	124 (13.41)	*3.01*	*
Verbal	50 (12.83)	67 (9.68)	*4.19*	***
Performance	52 (13.36)	56 (6.98)	*1.10*	
Standardised literacy tests				
Reading (WORD standardised scores)	44.05 (5.46)	52.29 (2.67)	*5.21*	***
Spelling (WORD standardised scores)	32.20 (6.23)	43.07 (2.59)	*6.15*	***
Phonological assessments (PhAB)				
Rhyme (standardised scores)	19.00 (2.18)	20.14 (0.86)	*1.86*	
Spoonerisms (standardised scores)	21.40 (5.83)	26.43 (3.44)	*2.89*	*
Rhyme (alliteration)	10.40 (4.85)	16.21 (4.69)	*3.49*	**
Fluency (alliteration)	15.00 (5.35)	18.29 (4.89)	*1.82*	
Cerebellar tests				
Bead threading (time in secs)	107.35 (16.80)	99.79 (13.57)	*-1.39*	
Thumb movement (time in secs)	18.80 (4.06)	13.43 (3.06)	*-4.18*	***

Table 1. Summary of psychometric data from dyslexic and control group. Standard deviations are shown in parentheses. WISC-III = Wechsler Intelligence Scale for Children– III; WORD = Wechsler Objective Reading Dimensions; n.s. = not significant; * $p<.01$; ** $p<.005$; *** $p<.001$.

Client information				SPELLING			
Subject Name	**DOB**	**Age at tes**	**Sex**	**homsyn**	**homsyn**	**homsyn**	**WRAT**
				Total	*Synonym*	*Homophone*	
Rowena Tinn	4/25/1987	18	F	61	36	25	12
Rupert Muldoon	12/29/1981	24;2	M	63	38	54	22
Matthew Willcock	1/14/1986	20;1	M	66	39	27	22
Rebecca Graham	6/18/1983	22;8	F	93	52	41	35
Sascha Muldoon	7/25/1984	21;7	M	82	48	34	27
Jason Pallman	7/10/1985	20;7	M	86	47	39	27
Luke Baghdadi	10/16/1986	19;4	M	80	47	33	26
Marc Stroud	4/1/1974	31;11	M	100	53	47	28
Fiona Clancy	8/4/1980	25;8	F	84	50	34	27
Leila Cooper	10/20/1983	22;4	F	76	45	31	20
Caswell Barry	12/2/1977	28;2	M	89	48	41	25
Asif Mahmood	10/18/1983	22;4	M	78	43	35	26
Dan Tubb	10/6/1979	26;4	M	81	47	34	23
Phillippa Goodwin	7/27/1981	24;7	F	88	51	37	33
Catherine Clark	4/25/1987	18;10	F	68	41	27	23
Charles Bryant	12/28/1983	22;2	M	8	3	5	1
Beatrix Sneller	2/17/1981	25;1	F	86	48	38	32
Alex Dyer	2/7/1984	22;1		76	45	31	25
Paul Rainbow	7/13/1954	51;7	M	101	53	48	35
Beatrice Holt	7/11/1981	24;7	F	83	47	36	31
Tom Schofield	7/9/1976	29;7	M	101	54	47	33
Andrew Viggars	9/23/1981	25;5	M	102	54	48	35
Kevin Tierney	11/3/1984	21;3	M	98	54	44	32
Nicole Smith	7/21/1955	50;7	F	100	54	46	35
Brian Murphy	3/16/1936	69;11	M	101	54	47	33
John Troughton	2/2/1941	65;1	M	100	54	46	35
Daniel Howell	6/10/1987	18;7	M	77	44	33	25
Jo Munday	8/4/1981	24;7	F	99	53	46	37
Fiona Richardson	8/25/1978	27;7	F	85	50	35	32
Srilogini Saivathan	2/10/1984	22;1	F	98	52	46	31
Nilufa Ali	10/31/1979	26;5	M	98	51	46	34
Norman Price	7/31/1932	73;8	M	85	47	38	
Janet Price	6/15/1931	74;9	F	98	54	44	
Hilary Button	9/25/1947	58;6	F	101	54	47	34
Sally Winter	3/18/1939	67;0	F	102	54	48	39
Marsha Quallo	3/19/1983	25;11	F	91	52	39	29
Jyotie Chand	17/02/1984	22,1	F	86	46	40	28

	control
	dyslexic (full)

		READING						
Graded Di	**Nonword**	**homsyn**	**homsyn**	**homsyn**	**WRAT**	**WTAR**	**NART**	**Nonword**
		Total	*Synonym*	*Homophone*				
10	4	81	45	36	25	24	24	11
16	8	101	54	47	34	38	34	19
13	6	101	54	47	31	35	25	23
25	8	102	54	48	40	48	42	25
20	6	101	53	48	37	40	38	25
21	5	100	54	46	29	34	27	21
15	5	99	54	45	30	31	28	19
24	6	102	54	48	38	40	30	24
19	6	102	54	48	40	44	36	23
11	4	100	53	47	34	31	29	18
20	5	102	54	48	39	42	40	23
19	4	100	53	47	29	25	18	16
19	5	101	53	48	35	33	35	18
24	10	101	54	47	35	43	33	24
15	8	100	53	47	27	32	24	19
2		4	2	2				
25	4	101	53	48	38	46	34	25
14	5	101	54	47	34	42	37	20
29	8	102	54	48	41	47	43	23
22	3	101	54	47	34	38	34	24
26	10	102	54	48	42	49	49	25
29	14	102	54	48	41	50	49	25
26	8	100	53	47	45	41	50	19
25	7	102	54	48	40	47	43	23
26	11	102	54	48	40	45	46	25
25	6	102	54	48	39	47	45	24
18	5	102	54	48	32	28	22	25
28	11	102	54	48	41	45	43	25
22	10	102	54	48	39	45	45	23
25	5	102	54	48	33	39	36	22
24	6	102	54	48	35	47	46	24
21	8	98	53	45	36	40	37	22
27	3	102	54	48	39	49	45	25
24	5	101	53	48	41	50	46	23
29	6	102	54	48	42	49	50	25
16	6	102	54	48	32	41	49	24
21	9	100	53	47	32	35	32	23

PhAB				PHONETIC			
Pictures		**Digits**		**Spoonerisms**	**Non-word Rep**		
1	2	1	2				
50	50	49	48	0	22		
49	49	50	50	13	35		
50	50	50	49	20	29		
50	50	48	50	21	32		
50	50	50	50	22	31		
50	50	50	50	18	32		
50	50	49	50	17	34		
49	50	50	50	24	33		
50	50	50	50	6	34		
50	50	50	50	8	31		
49	50	50	50	22	32		
50	49	49	47	16	17		
50	50	50	50	16	29		
50	50	50	50	24	32		
50	50	50	50	14	22		
48	50	50	50	0			
50	50	50	50	22	38		
50	50	50	50	20	37		
50	50	50	50	24	31		
50	47	49	50	21	36		
50	49	50	50	23	36		
50	50	50	50	21	30		
50	50	50	50	19	28		
50	50	50	50	14	32		
50	50	50	50	18	32		
50	50	50	49	15	23		
50	50	50	50	20	34		
50	49	50	49	22	33		
49	47	50	50	13	35		
50	50	50	49	22	34		
50	50	50	50	24	40		
				20	24		
50	50	50	50	24	31		
50	50	50	50	22	30		
47	50	48	50	23	33		
50	50	50	50	20	36		

Forename	Surname	DOB	Age at testing	Sex	RAW SCORES			
					Picture Cc	Vocabular	Digit Symb	Similaritie
Nilufa	Ali	10/31/1979	26,5	F	21	47	96	27
Luke	Baghdadi	10/16/1986	19,5	M	20	34	75	20
Caswell	Barry	12/2/1977	28,2	M	22	57	104	27
Hilary	Britton	9/25/1947	58,6	F	19	57	105	24
Charles	Bryant	12/28/1983	22,2	M	25	49	61	27
Jyoti	Chand	2/27/1984	22,0	F	19	38	81	25
Fiona	Clancy	8/4/1980	25,8	F	17	55	63	26
Catherine	Clark	4/25/1987	18,10	F	20	38	65	24
Leila	Cooper	10/20/1983	22,4	F	22	47	94	25
Alex	Dyer	2/7/1984	22,1	M	21	40	76	29
Phillippa	Goodwin	7/27/1981	24,6	F	22	50	101	25
Rebecca	Graham	6/18/1983	22,8	F	24	54	97	29
Dan	Howell	6/10/1987	18,8	M	20	36	95	28
Asif	Mahmood	10/18/1983	22,3	M	19	39	62	26
Rupert	Muldoon	12/29/1981	24,1	M	24	50	85	27
Sascha	Muldoon	7/25/1984	21,6	M	23	53	78	29
Joanna	Munday	8/4/1981	24,7	F	22	58	92	26
Brian	Murphy	3/16/1936	69,11	M	20	49	61	26
Paul	Rainbow	7/13/1954	51,8	M	19	51	97	27
Fiona	Richardson	8/25/1978	27,5	F	20	54	89	28
Srilogini	Saivanathan	2/10/1984	22,0	F	20	42	94	23
Tom	Schofield	7/9/1976	29,7	M	24	57	88	32
Nicole	Smith	7/21/1955	50,7	F	21	53	68	20
Bea	Sneller	2/17/1981	25,1	F	22	48	97	28
Marc	Stroud	4/1/1974	31,11	M	22	42	46	23
Kevin	Tierney	11/3/1984	21,3	M	23	55	84	28
Rowena	Tinn	4/25/1987	18,9	F	20	51	88	25
John	Troughton	2/2/1941	65,1	M	21	57	86	28
Dan	Tubb	10/6/1979	26,4	M	21	54	81	25
Andrew	Viggars	9/23/1980	25,5	M	20	56	78	19
Matthew	Willcock	1/14/1986	20,1	M	22	36	73	22
Sally	Winter	3/18/1939	67,0	F	17	55	108	28

							SCALED SCORES - V	
Block Des	Arithmetic	Matrix Rea	Digit Span	Informatio	Picture Ar	Comprehe	Vocabular	Similaritie
50	17	22	24	20	15	17	12	12
45	16	22	19	16	19	23	10	9
60	18	24	18	27	18	26	15	12
55	20	13	25	23	16	26	14	11
53	16	18	18	26	14	22	13	13
57	20	22	20	20	17	23	10	11
50	14	22	20	20	20	25	14	12
37	10	16	10	20	6	19	10	11
62	15	22	17	20	17	24	12	11
65	18	22	13	23	22	17	11	15
55	18	20	22	17	20	27	13	11
51	17	21	12	25	18	26	15	15
61	17	22	15	21	20	21	10	14
42	20	22	13	22	15	19	11	12
57	9	18	16	19	20	17	13	13
63	16	21	19	22	18	22	14	15
63	19	24	20	23	17	25	16	12
33	18	16	22	24	16	23	12	13
57	19	21	25	26	17	28	11	12
54	13	20	14	20	14	21	14	13
42	17	18	18	23	18	20	11	10
48	18	23	23	26	22	27	15	17
47	13	18	14	23	12	26	12	8
58	15	24	16	24	20	22	12	13
49	16	22	18	22	18	17	10	10
67	18	21	21	23	22	26	15	14
49	21	22	11	25	18	23	14	11
43	16	14	12	25	18	26	14	14
61	17	23	10	22	16	25	14	11
52	21	24	26	23	17	23	15	8
64	16	21	17	15	20	18	10	10
51	16	22	22	20	8	25	13	14

erbal				SCALED SCORES - Performance				
Arithmetic	Digit Span	Informatio	Comprehe	Picture Co	Digit Syml	Block Des	Matrix Rea	Picture Ar
12	15	13	9	11	14	12	14	10
12	11	11	12	9	9	11	14	13
13	10	17	14	12	15	15	16	11
16	16	13	13	10	19	15	10	13
12	10	17	12	18	7	13	11	9
16	12	13	12	8	10	14	14	11
11	12	13	13	7	7	12	14	14
8	5	13	10	9	7	9	10	5
11	10	13	13	12	13	16	14	11
14	7	15	9	11	9	17	14	17
14	13	11	15	12	14	13	12	15
13	6	16	14	15	13	12	13	12
13	8	13	11	9	13	15	14	15
16	7	14	10	8	7	10	14	10
7	9	12	9	15	11	14	11	15
12	11	14	12	13	10	16	13	12
15	12	15	13	12	12	16	16	11
14	14	14	15	11	11	11	13	14
14	16	15	14	9	15	16	14	13
10	8	13	11	9	12	13	12	9
13	10	15	11	9	13	10	11	12
13	14	16	14	15	12	11	15	17
9	8	13	12	11	10	13	12	9
11	9	15	11	12	14	14	16	14
12	11	13	8	12	5	12	14	12
14	12	15	14	13	11	18	13	17
17	6	16	12	9	11	12	14	12
12	7	15	13	12	16	13	12	16
12	5	14	13	11	11	15	15	10
16	16	14	12	9	10	12	16	11
12	10	10	10	12	9	17	13	15
12	14	12	12	10	19	15	16	9

SUMS OF SCALED SCORES			IQ SCORES		
Verbal	Performan	Full	VIQ	PIQ	FSIQ
73	61	134	113	114	114
65	56	121	104	107	106
81	69	150	122	127	127
83	67	150	124	124	127
77	58	135	117	110	115
74	57	131	114	109	112
75	54	129	115	105	111
57	40	97	96	86	91
70	66	136	110	122	116
71	68	139	111	125	118
77	66	143	117	122	121
79	65	144	119	121	122
69	66	135	108	122	115
70	49	119	110	98	104
63	66	129	102	122	111
78	64	142	118	119	120
83	67	150	124	124	127
82	60	142	123	113	120
82	67	149	123	124	126
69	55	124	108	106	108
70	55	125	110	106	108
89	70	159	133	128	135
62	55	117	101	106	103
71	70	141	111	128	120
64	55	119	103	106	104
84	72	156	125	132	132
76	58	134	116	110	114
75	69	144	115	127	122
69	62	131	108	116	112
81	58	139	122	110	118
62	66	128	101	122	110
77	69	146	117	127	123